

would have been denoted as extrinsic and mixtrinsic, respectively. Each mode is characterized by a different combination of advantages and disadvantages.

- In one mode, evolution occurs entirely by computational simulation. For example, circuits can be computationally modeled as consisting only of negative-channel metal oxide semiconductor (NMOS) and positive-channel metal oxide semiconductor (PMOS) transistors that can be connected in arbitrary topologies. The advantage of this mode is that it enables free exploration of the search space, with few or no topological restrictions like those that occur in practice; the lack of restrictions can favor the emergence of new designs. The disadvantage of this approach is that there is no implementation of evolved designs in hardware.

- In the other mode, the circuit topologies are restricted to those of field-programmable transistor arrays (FPTAs). Evolution involves both (1) simulations on computational models of FPTAs and (2) experiments on real FPTAs that are constructed and tested in efforts to implement the models. The advantages of this mode are that circuits can be implemented in practice after evolution, and FPTA chips can be reconfigured to map different polymorphic gates onto them, as needed. The disadvantages of this mode are that (1) the topologies are restricted and (2) in some cases, circuits evolved taking account of the nonideal characteristics (e.g., non-zero "ON" resistances and finite "OFF" resistances of transistor switches) of realistic components can be more complicated than those

evolved through models of ideal components.

This work was done by Adrian Stoica of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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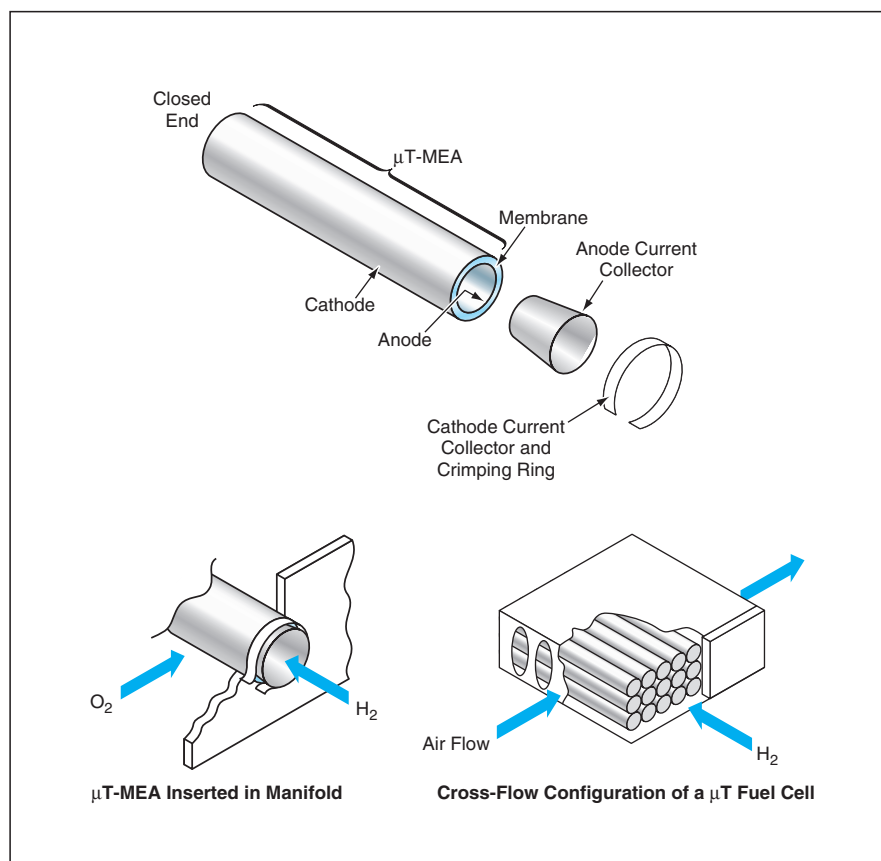
Micro-Tubular Fuel Cells

Power densities would be much greater than those of conventional fuel cells.

Lyndon B. Johnson Space Center, Houston, Texas

Micro-tubular fuel cells that would operate at power levels on the order of hundreds of watts or less are under development as alternatives to batteries in numerous products — portable power tools, cellular telephones, laptop computers, portable television receivers, and small robotic vehicles, to name a few examples. Micro-tubular fuel cells exploit advances in the art of proton-exchange-membrane fuel cells. The main advantage of the micro-tubular fuel cells over the plate-and-frame fuel cells would be higher power densities: Whereas the mass and volume power densities of low-pressure hydrogen-and-oxygen-fuel plate-and-frame fuel cells designed to operate in the targeted power range are typically less than 0.1 W/g and 0.1 kW/L, micro-tubular fuel cells are expected to reach power densities much greater than 1 W/g and 1 kW/L. Because of their higher power densities, micro-tubular fuel cells would be better for powering portable equipment, and would be better suited to applications in which there are requirements for modularity to simplify maintenance or to facilitate scaling to higher power levels.

The development of PEMFCs has conventionally focused on producing large stacks of cells that operate at typi-



A Micro-Tubular Fuel Cell contains multiple tubular membrane/electrode assemblies that operate in an oxygen/hydrogen cross flow. The hydrogen manifold and the edge-tab electrical current collectors take up much less space than do the bipolar plates of conventional plate-and-frame fuel cells.

cal power levels >5 kW. The usual approach taken to developing lower-power PEMFCs for applications like those listed above has been to simply shrink the basic plate-and-frame configuration to smaller dimensions. A conventional plate-and-frame fuel cell contains a membrane/electrode assembly in the form of a flat membrane with electrodes of the same active area bonded to both faces. In order to provide reactants to both electrodes, bipolar plates that contain flow passages are placed on both electrodes. The mass and volume overhead of the bipolar plates amounts to about 75 percent of the total mass and volume of a fuel-cell stack. Removing these bipolar plates in the micro-tubular fuel cell significantly increases the power density.

A micro-tubular fuel cell contains multiple membrane/electrode assemblies, each comprising a tubular proton-exchange membrane with the anode on the inner surface and the cathode on the outer surface (see figure). Targeted dimensions include an inner membrane diameter of 600 μm , membrane thickness of 50 μm , anode thickness of 25 μm , and cathode thickness of 125 μm . One end of each micro-tubular mem-

brane/electrode assembly ($\mu\text{T-MEA}$) is closed, while the other end is open and connected to a current-collection manifold. At the open end of each $\mu\text{T-MEA}$, a conical anode current collector and diffuser is inserted in the tube, and a cathode current-collector/crimping ring is placed around the outside of the tube. Hydrogen gas diffuses into the interiors of the tubes, while air or oxygen is blown across the outside of the tubes in a cross-flow configuration.

The anode and cathode current collectors are connected by an end-plate assembly (not shown in the figure) in the hydrogen-gas manifold that defines the parallel and serial electrical connections of the $\mu\text{T-MEAs}$. Because each $\mu\text{T-MEA}$ produces a relatively small current, parallel and serial connections can be made at their ends without incurring an unacceptably large amount of ohmic heating. Although the cylindrical geometry causes the current density at the anode in each $\mu\text{T-MEA}$ to exceed that at the cathode, this feature detracts only slightly from cell performance because it is a fundamental property of any PEMFC that the anode polarization loss is much less than the cathode polarization loss at a given current density.

The elimination of the bipolar plates in favor of the much less bulky and massive manifold and current-collector assembly is the single greatest contribution to more efficient utilization of available volume and thus to increased power density. It has been estimated that after further optimization of dimensions, materials, and fabrication processes, it should be possible to make micro-tubular fuel cells with power densities as great as 6.4 W/g and 6.9 kW/L.

This work was done by Michael C. Kimble, Everett B. Anderson, Karen D. Jayne, and Alan S. Woodman of Physical Sciences Inc. for Johnson Space Center. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.

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Whispering-Gallery-Mode Tunable Narrow-Band-Pass Filter

Characteristics include wide tuning range, short tuning time, and compactness.

NASA's Jet Propulsion Laboratory, Pasadena, California

An experimental tunable, narrow-band-pass electro-optical filter is based on a whispering-gallery resonator. This device is a prototype of tunable filters needed for the further development of reconfigurable networking wavelength-division multiplexers and communication systems that utilize radio-frequency (more specifically, microwave) subcarrier signals on optical carrier signals. The characteristics of whispering-gallery resonators that make them attractive for such applications include high tuning speed, compactness, wide tuning range, low power consumption, and compatibility with single-mode optical fibers. In addition, relative to Fabry-Perot resonators, these devices offer advantages of greater robustness and lower cost.

As described in several prior *NASA Tech Briefs* articles, a whispering-gallery resonator is a spheroidal, disklike, or toroidal body made of a highly transparent material. It is so named because it is designed to

exploit whispering-gallery electromagnetic modes, which are waveguide modes that propagate circumferentially and are concentrated in a narrow toroidal region centered on the equatorial plane and located near the outermost edge.

The experimental whispering-gallery tunable filter (see figure) is made from a disk of Z-cut LiNbO_3 of 4.8-mm diameter and 0.17-mm thickness. The perimeter of the disk is rounded to a radius of curvature of 100 μm . Metal coats on the flat faces of the disk serve as electrodes for exploiting the electro-optical effect in LiNbO_3 for tuning. There is no metal coat on the rounded perimeter region, where the whispering-gallery modes propagate. Light is coupled from an input optical fiber into the whispering-gallery modes by means of a diamond prism. Another diamond prism is used to couple light from the whispering-gallery modes to an output optical fiber. This device is designed and operated to

exploit transverse magnetic (TM) whispering-gallery modes, rather than transverse electric (TE) modes because the resonance quality factors (Q values) of the TM modes are higher. If Q values were not of major concern, it would be better to use the TE modes because the electro-optical shifts of the TE modes are 3 times those of the TM modes.

Although this filter has been operated only at wavelengths in the vicinity of 1.55 μm , it is capable of operating at wavelengths from ≈ 1.0 to ≈ 1.7 μm — a range limited only by absorption of light in LiNbO_3 . The free spectral range [FSR (the frequency interval between successive resonances)] of the filter is 10 GHz and the bandwidth is 30 MHz; these figures translate to a finesse of about 300. In contrast, a typical Fabry-Perot filter has a finesse of 100 and a bandwidth of 125 MHz. (The finesse is the ratio between the FSR and the bandwidth. It is commonly used as a figure of merit of a